PB84-102383

Plant Water Status Influences Ozone Sensitivity of Bean Plants

(U.S.) Corvallis Environmental Research Lab., OR

1982

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before compl

1. REPORT NO.	2.	PB84-102383
EPA-600/J-82-380		

4. TITLE AND SUBTITLE	5. REPORT DATE
Plant Water Status Influences Ozone Sensitivity of Bean Plants. (Journal Version)	1982
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
David T. Tingey, Gail L. Thutt, Marcia L. Gumpertz, and William E. Hogsett	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
Environmental Research Laboratory U.S. Environmental Protection Agency Corvallis, Oregon 97333	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Environmental Research Laboratory U.S. Environmental Protection Agency Corvallis, Oregon 97333	inhouse
	14. SPONSORING AGENCY CODE
	EPA/600/02

15. SUPPLEMENTARY NOTES

Published in Agriculture and Environment, 7: 243-254, 1982

16. ABSTRACT

Studies were conducted in a controlled environment chamber to determine the association between plant water status and ozone sensitivity. Bean plants were subjected to various water stress regimes for 4 to 10 days using a semipermeable membrane system which controlled plant water status and then exposed to ozone. Ozone sensitivity was measured using stress ethylene which was highly correlated with foliar injury. Plant water stress decreased plant sensitivity to ozone; complete protection was attained within 1 to 3 days depending on the level of water stress. When water stress was removed, the plants regained ozone sensitivity equal to nonwater stressed plants within 6 days. The decreased ozone sensitivity was associated with only a small change in leaf water potential. The reduced sensitivity following water stress was apparently associated with a decreased leaf conductance reducing ozone uptake.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Release to public	unclassified	13
	20. SECURITY CLASS *(This page)*	22. PRICE
	unclassified	

REPRODUCED BY
NATIONAL TECHNICAL INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

EPA Form 2220-1 (9-73)

EPA-600/J-82-380
JOURNAL ARTICLE

Agriculture and Environment, 7 (1982) 243—254
Elsevier Scientific Publishing Company, Amsterdam — Printed in The Netherlands

PLANT WATER STATUS INFLUENCES OZONE SENSITIVITY OF BEAN PLANTS

DAVID T. TINGEY, GAIL L. THUTT, MARCIA L. GUMPERTZ and WILLIAM E. HOGSETT

U.S. Environmental Protection Agency and Northrop Services, Inc., 200 S.W. 35th Street, Corvallis, OR 97333 (U.S.A.)

(Accepted 23 March 1982)

ABSTRACT

Tingey, D.T., Thutt, G.L., Gumpertz, M.L. and Hogsett, W.E., 1982. Plant water status influences ozone sensitivity of bean plants. *Agric. Environm.*, 7: 243—254.

Studies were conducted in a controlled environment chamber to determine the association between plant water status and ozone sensitivity. Bean plants were subjected to various water stress regimes for 4 to 10 days using a semipermeable membrane system which controlled plant water status and then exposed to ozone. Ozone sensitivity was measured using stress ethylene which was highly correlated with foliar injury. Plant water stress decreased plant sensitivity to ozone; complete protection was attained within 1 to 3 days depending on the level of water stress. When water stress was removed, the plants regained ozone sensitivity equal to nonwater stressed plants within 6 days. The decreased ozone sensitivity was associated with only a small changes in leaf water potential. The reduced sensitivity following water stress was apparently associated with a decreased leaf conductance reducing ozone uptake.

INTRODUCTION

Ozone sensitivity is influenced by environmental factors during both plant growth and exposure. In field studies, tobacco (*Nicotiana tabacum* L.) plants exhibited more foliar oxidant injury from ambient exposures when grown in moist soils than comparable plants grown in drier soils (Taylor et al., 1960; Dean and Davis, 1967; Walker and Vickery, 1961). Foliar oxidant injury increased proportional to the amount of irrigation water applied (Walker and Vickery, 1961; Dean and Davis, 1967). A few days of soil moisture stress prevented weather fleck injury in tobacco (Taylor et al., 1960). In greenhouse studies, well-watered plants were compared to ones in which the soil was allowed to dry to near the wilting point or to a specific percentage of field capacity. Using these approaches, plants that were water stressed just prior to ozone exposure exhibited little or no foliar injury compared to well-watered plants (Khatamian et al., 1973; Markowski and Grzesiak, 1974; Harkov and Brennan, 1980; Olszyk and Tibbitts, 1981).

0304-1131/82/0000—0000/$02.75 1982 Elsevier Scientific Publishing Company

In the above cited studies and others (i.e., Rich and Turner, 1972; Adedipe et al., 1973), a reduction in stomatal aperture or leaf conductance was suggested as the cause of decreased sensitivity. However, in the majority of the studies, neither water potential (soil or plant) nor leaf conductance were measured. In addition, the experiments were not conducted under conditions that favored reproducibility of the plant water status between experiments or locations.

The objective of our research was to determine the effects of plant water stress on the plant sensitivity to ozone using a cultural system in which the plants were grown at defined and reproducible levels of soil water potential (Tingey and Stockwell, 1977). The cultural system accommodated the use of various soil water potential levels and plant water stress regimes. Ozone sensitivity was correlated with other measures of plant water status such as leaf conductance and leaf water potential.

METHODS AND MATERIALS

Plant growth

Beans (*Phaseolus vulgaris* L. cv. 'Pinto 111') were grown from seed in tubular plastic containers (Super Cells, volume of 175 cm^3) and watered daily with North Carolina State University Phytotron nutrient solution (Downs and Hellmers, 1975). The plants were grown in a controlled environment chamber on a 16-h light/8-h dark cycle with a photosynthetic photon flux density of approximately 380 $\mu E\ m^{-2}\ s^{-1}$ at canopy height. Day and night temperatures averaged 23.5 ± 1 and 18.5 ± 1°C, respectively.

Experimental procedure

Plants were subjected to water stress as described by Tingey and Stockwell (1977) except that the larger "Super Cells" were used. Between 14 to 18 days from seeding, the plants had well-developed root systems and were transferred into modified tubular plastic containers. The container had approximately 65% of the surface area removed and they were enclosed in water-rinsed semipermeable cellulose membrane tubing (Spectrapor 1, minimum molecular weight exclusion limit 6000—8000 daltons). After the root-vermiculite masses were encased in the membranes, they were placed with in individual 2-l plastic containers (Fig. 1) filled with either nutrient solution or nutrient solution to which various concentrations of polyethylene glycol (PEG) 20M (average molecular weight 14000—16000) were added to control the osmotic potential (—80 to —300 kPa). The osmotic potential of the solution was manipulated to control the matric soil-water potential within the semipermeable membrane and thereby control plant water status (Zur, 1966, 1967). In the solution, the membrane collapsed against the root-vermiculite mass, providing good contact between membrane and

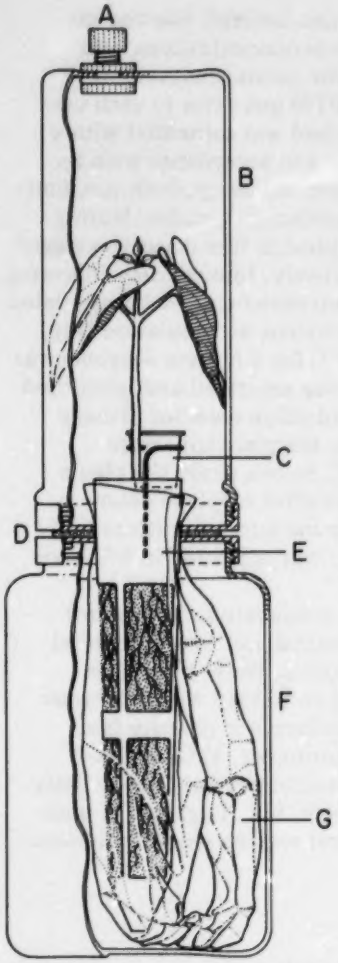

Fig. 1. Ethylene encapsulation chamber and modified Super Cell with semipermeable membrane for controlling plant water status: (a) ethylene sampling port; (b) 1-l encapsulation chamber; (c) container of CO_2 absorbant; (d) double container lids glued back-to-back; (e) modified Super Cell; (f) 2-l polyethylene container; (g) semipermeable membrane that enclosed plant roots.

the root-vermiculite mass.

The plants were subjected to various water stress regimes within the membrane enclosures for up to 10 days (typically 7 days) prior to ozone exposure at the same environmental conditions as they were grown. The plants were exposed to ozone (0 to 1.0 $\mu l\ l^{-1}$ for 2 h) in greenhouse exposure chambers as previously described (Tingey et al., 1976). Ozone gen-

erated by the ultraviolet light irradiation of air was metered into the exposure chambers to maintain the desired gas phase concentrations, and measured using chemiluminescence analyzers. The ozone analyzers were calibrated with a transfer standard (McElroy, 1979) just prior to each use at the desired concentrations. The transfer standard was calibrated with a dedicated "UV Standard" operated and calibrated in accordance with the procedures of Paur and McElroy (1979). To insure accuracy, both standards (UV and transfer) were subjected to periodic performance audits. During exposures, air temperature and photosynthetic photon flux density averaged approximately 26° C and 350 μE m^{-2} s^{-1}, respectively. Immediately following exposure plants were removed from the exposure chambers and encapsulated in clear 1-l polymethylpentene containers for ethylene accumulation (Fig. 1). The plants were incubated in the dark at 26° C for 2 h, then ethylene was sampled using 1-ml gastight syringes. Ethylene was separated and quantified using gas—solid chromatography and a flame ionization detector (Tingey et al., 1978). Following ethylene measurements, the plant tops were removed and dried to a constant weight at 70° C. In one study the plants were removed from the encapsulation containers after ethylene determinations and held for an additional 72 h under the same conditions in which they were grown, then visual foliar injury was estimated in 5% increments.

To determine plant water status and growth, a separate set of control plants was maintained under the same environmental and water potential conditions as the plants used in the exposure studies. Water potentials (first trifoliate leaf or plant top) were estimated at midday with a pressure chamber (Waring and Cleary, 1967) and leaf conductance (usually first trifoliate leaf) was measured with a diffusion porometer (MK3, Delta-T Devices, Cambridge, Great Britain). Solution osmotic potentials were determined using a Wescor C52 sample chamber (Wecor, Inc., Logan, UT) operating in the dewpoint mode and calibrated against sodium cloride solutions of known potentials (Lang, 1967).

Data analysis

The experiments were designed as randomized blocks with two plants per treatment in each replicate; each experiment consisted of three to four replicates. The response variables were transformed to their respective logarithms prior to statistical analyses to stabilize the variances (Snedecor and Cochran, 1967); then analysis of variance was carried out for each experiment. To characterize the response of ozone concentrations on the plants, linear and quadratic regression coefficients were estimated. For comparisons among water stress treatments, multiple comparison procedures were used: Dunnett's test (Dunnett, 1955) for comparisons of individual treatment means with a control and the Newman—Keul procedure (Anderson and McLean, 1974) for all others. Comparisons were performed at the 0.05 significance level.

RESULTS

The initial studies conducted to confirm the association between stress ethylene production and foliar injury indicated that stress ethylene production increased log-linearly as foliar injury increased, with a high correlation ($r = 0.955$) between the two measures (Fig. 2). Because of this close association, stress ethylene was used as a primary measure of ozone response in subsequent studies. To determine if water-stressed plants maintained the ability to produce ethylene, plants were grown in −35 and −80 kPa solutions for 7 days, then attached primary leaves were dipped in solutions (concentrations 0 to 200 μM) of indolaecetic acid (IAA) or 1-aminocyclopropane-1-carboxylic acid (ACC). Both compounds stimulated ethylene production when the plants were treated at concentrations of 20 μM or greater, indicating that the water-stressed plants maintained the ability to produce ethylene (Yang, 1980).

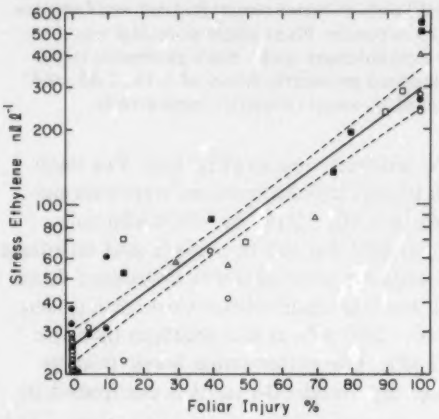

Fig. 2. The correlation between foliar injury and stress ethylene production. The plants were grown at solution osmotic potentials ranging from −35, to −300 kPa for 7 days and the exposed to ozone, 0.0 to 1.0 μl l^{-1} ozone for 2 h. Stress ethylene production was measured immediately following exposure and foliar injury on the first trifoliate 72 h later. The symbols indicate different replications of the experiment.

To evaluate the association between ozone sensitivity and plant water stress, plants were subjected to −35, to −300 kPa solutions for 7 days, then exposed to ozone. The unstressed bean plants (−35 kPa) exhibited a significant increase in stress ethylene production with increasing ozone concentrations (Fig. 3a). However, the plants grown in solution osmotic potentials of −80 kPa or less for 7 days showed no increase in stress ethylene production, even when exposed to high ozone concentrations (1 μl l^{-1} for 2 h). There were no significant differences in ethylene production among the three water stress levels (−80, −210, or −300 kPa). Leaf conductance for the unifoliate

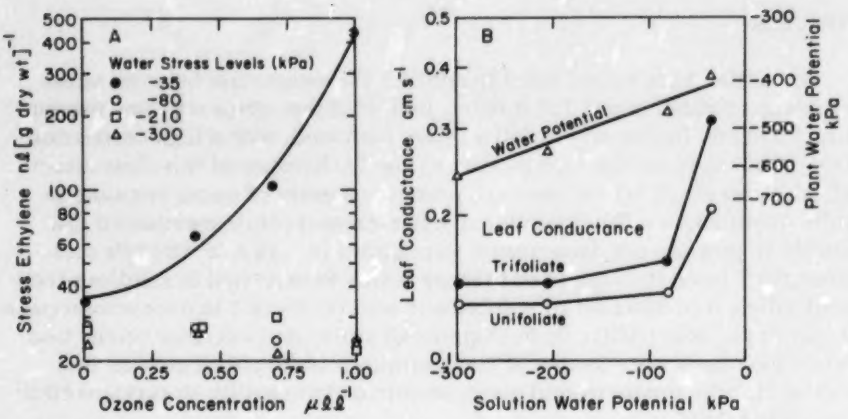

Fig. 3. The effects of water stress on ethylene production and plant water status. A: Change in stress ethylene with ozone at several levels of water stress. B: Leaf conductance and plant water potential of the plants prior to exposure. Plant water potential was measured on plant stems that were severed at the cotyledonary node. Each geometric mean was based on six to eight observations with standard geometric errors of 1.16, 1.03, and 1.03 for stress ethylene, leaf conductance, and plant water potential, respectively.

leaves was consistently less than for the trifoliate leaves (Fig. 3b). For each leaf type, conductances for the unifoliate and trifoliate leaves were not significantly different among plants grown in −80, −210, or −300 kPa solutions. Leaf conductances decreased 36 to 48% for the unifoliate and trifoliate leaves, respectively, when the solution osmotic potential was decreased from −35 to −80 kPa. Plant water potential was less than solution osmotic potential and decreased linearly from −390 to −620 kPa as the solution osmotic potential decreased from −80 to −300 kPa. The water stress levels that reduced ozone sensitivity also reduced top dry weight 34 to 40% compared to non-water stressed controls.

To determine the duration of water stress needed to induce protection from ozone injury, pinto beans were grown in −80 and −300 kPa for 0 to 7 days and then exposed to ozone. The ratio of ethylene production (ozone exposed/unexposed) in plants grown in −300 kPa solutions was essentially 1 at all times except day 0, indicating that the plants were not sensitive to ozone (Fig. 4a). The ozone sensitivity of plants grown in the −80 kPa solution decreased after 1 and 2 days in the solution, when the ratio of ethylene production dropped to approximately 3.4 and 1.8, respectively; by day 3 the plants in −80 kPa treatment were no longer sensitive to ozone and responded similarly to those in the −300 kPa solution. The reduction in ozone response at −300 kPa was associated with a large decrease in leaf conductance from 0.53 cm s^{-1} at day 0 to 0.2 cm s^{-1} at day 1, and remained essentially constant for the rest of the study (Fig. 4b). For plants grown at −80 kPa, leaf conductance decreased about 50% between day 0 and day 1, but not until

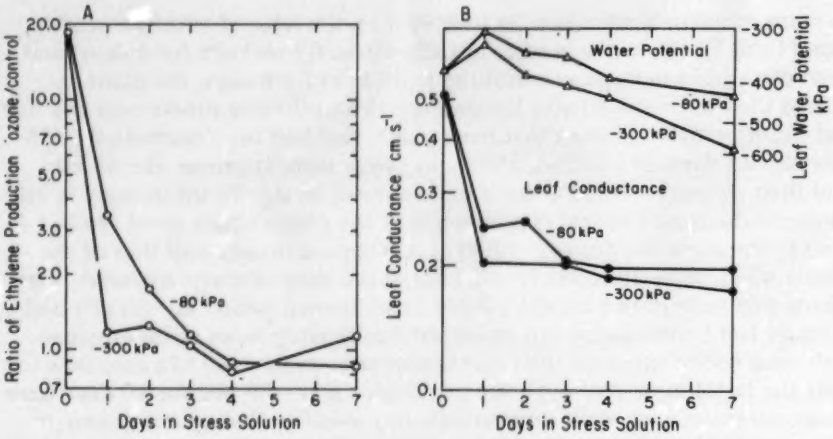

Fig. 4. The change in stress ethylene and plant water stress with duration of water stress. A: Ozone-sensitivity as function of water stress duration. A ratio of ethylene production significantly larger than 1.0 indicated a significant ozone response. B: Leaf conductance and leaf water potential of the first trifoliate prior to exposure as a function of water stress duration. Each geometric mean was based on six observations with standard geometric errors of 1.26, 1.08, and 1.05 for stress ethylene, leaf conductance and leaf water potential, respectively.

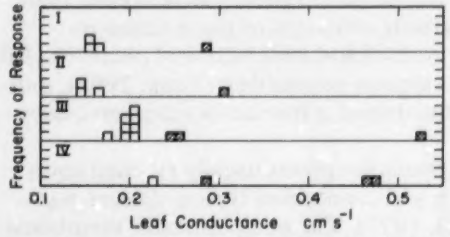

Fig. 5. Association between leaf conductance and ozone sensitivity. Mean stomatal conductances from treatments (−35 kPa) producing significant ozone responses (stimulated stress ethylene production) at 1.0 μl l^{-1} are compared with water stress treatments that decreased the ozone sensitivity. Each hatched square indicates a treatment with significant ozone response while each open square indicates a treatment that did not respond to ozone. The data for each of four separate experiments are shown.

day 3 was it similar to the plants grown in −300 kPa solutions. Leaf water potentials (Fig. 4b) were not significantly different between the solutions over time, except for plants grown at −300 kPa for 7 days, which was significantly less than at day 0.

Plants were subjected to various water stress regimes to determine if plants regained their ozone sensitivity when the water stress was removed. Plants grown at −35 kPa for 10 days and exposed to ozone showed a large increase

in stress ethylene production, as indicated by the ratio of ethylene production (Table I). When plants were initially stressed (−80 kPa for 4 days) and then placed in a unstressed condition (−35 kPa) for 6 days, the plant regained their ozone sensitivity because the stress ethylene production was not significantly different than that from plants that had been unstressed (−35 kPa) for 10 days. In contrast, plants that were initially grown at −35 kPa and then stressed (−80 kPa) for 4 days showed no significant increase in ethylene production. The leaf conductance of the plants which spent the last 4 days in the stress condition (−80 kPa) was approximately half that of the plants which were unstressed (−35 kPa) at the time of ozone exposure. The plants that were grown for the 10-day experimental period at −80 kPa had a higher leaf conductance and produced significantly more stress ethylene following ozone exposure than plants that were in the −80 kPa solutions for only the last 4 days. Although the plants grown at −80 kPa for 10 days were ozone sensitive, they were substantially less sensitive than plants grown in the unstressed conditions for the last 6 days of the study.

DISCUSSION

Stress ethylene has been used to determine ozone responses (Tingey et al., 1976; Stan et al., 1981) and it is correlated with visual injury, chlorophyll loss, and decreased plant growth (Tingey, 1980). In this study, good log–linear correlation between visual injury and stress ethylene was obtained, indicating that it can be used to obtain reliable estimates of plant ozone responses. The similar responses of the control and water-stressed plants to IAA and ACC, compounds that stimulate ethylene production (Yang, 1980), indicated that the water stressed plants maintained a functional ethylene biosynthetic pathway.

In the semipermeable membrane system the plants usually reached equilibrium with the solutions within 24 h and maintained typical diurnal plant water relations (Tingey and Stockwell, 1977). The semipermeable membrane system allowed the passage of nutrients for plant uptake and excluded PEG, preventing any direct interference with plant metabolism (Zur, 1966, Tingey and Stockwell, 1977). To compare the ability of the semipermeable membrane system to provide reproducible plant water status among experiments, the coefficients of variation (CV) for leaf water potential were computed for similar water stress treatments. The CV for plant water potentials ranged between 5 and 9% for plants grown at the same solution osmotic potentials in each of the four separate experiments, indicating good reproducibility among experiments. The leaf water potentials of our control plants (−35 kPa solution) in all experiments averaged −400 kPa and was similar to values measured in bean plants grown in hydroponic and well-watered soil systems (Rich and Turner, 1972; Hoffman et al., 1973). Bean plants grown in hydroponic systems at solution water potentials of −200 and −400 kPa exhibited leaf water potentials of −510 and −700 kPa (Hoffman et al., 1973); in our

experiments plants grown in −300 kPa solutions exhibited leaf water potentials of −580 kPa. The above data show good comparability among experiments within our laboratory and published data on bean plants, indicating that our membrane system provided typical plant water relations.

In this study, a reduction in leaf water potential from −400 kPa in the controls to approximately −450 kPa in the stressed plants (−80 kPa solutions) reduced the plant sensitivity to ozone. The plant water potentials of well-watered *Pisum sativum* L. were −340 kPa and water-stressed plants which displayed limited ozone injury had mean water potentials of −400 kPa (Olszyk and Tibbitts, 1981). In both studies, major changes in ozone sensitivity were associated with small changes in water potential.

In our study, the protection from ozone injury obtained within 1 to 4 days, depending on the severity of the water stress, was similar to previous results. In field studies, a few days of water stress was sufficient to protect the plants from oxidant injury (Taylor et al., 1960). In another study, when the concentrations of Hoagland's solution were changed from 1*x* to 8*x*, changing the osmotic potential around the plant roots, sunflower (*Helianthus annus* L.) plants gained protection from visual ozone injury within 1 h (Oertli, 1958).

Bean plants (Table I) regained their ozone sensitivity within 6 days after the removal of the water stress. A fairly rapid recovery of ozone sensitivity from water stress was also observed in field studies by oxidant injury occurring shortly after rainfall in water-stressed tobacco plants (Dean and Davis, 1967). Sunflower plants regained some oxidant sensitivity within 1 h when the concentration of the Hoagland nutrient solution was decreased from 8*x* to 1*x*, decreasing the osmotic potential around the roots (Oertli, 1958). Associated with the recovery of ozone sensitivity in bean plants following water stress removal was an increase in leaf conductance (Table I). The leaf conductances of water-stressed bean, sunflower, and soybean (*Glycine max* [L.] Merr) plants returned to prestress values within 4 days of watering (Moldau, 1973; Sionit and Kramer, 1976).

Before ozone can injure plants it must diffuse from the ambient air, though the stomata, into the leaf. The rate of diffusion is proportional to the ozone concentration gradient between the ambient air and leaf interior and the permeability of the diffusive pathway (leaf conductance). The stomata of water-stressed plants opened to a smaller degree, closed earlier in the day, and also more rapidly in the presence of ozone (MacDowall, 1965; Rich and Turner, 1972; Adedipe et al., 1973). These studies imply that ozone protection was obtained through the partial to complete closure of stomata, probably reducing the ozone influx into the leaf. Our results support this conclusion. For example, plants that were unstressed or initially stressed for the first 4 days had similar leaf conductances and ozone responses (Table I) whereas plants that were stressed for the last 10 or 4 days had lower leaf conductances and were less sensitive to ozone. To further illustrate this association, the mean leaf conductance of plants that were ozone sensitive (e.g.,

TABLE I

The effects of various water stress regimes on plant response to ozone

Treatment	Ratio of ethylene production O_3 treatment/control	Leaf conductance (cm s^{-1})	Leaf water potential (kPa)
−35 kPa for 10 days	23.2	0.45	−390
−80 kPa for 4 days + −35 kPa for 6 days	17.7	0.48	−470
−35 kPa for 6 days + −80 kPa for 4 days	1.5	0.23	−430
−80 kPa for 10 days	4.0	0.29	−480
SGE	1.21	1.15	1.06

Each geometric mean was based on at least six observations; SGE is a standard geometric error. Ethylene production was based on the whole plant; a ratio of ethylene production significantly larger than 1.0 indicated a significant plant response to ozone. Plants were exposed to 0 or 100 $\mu l\ l^{-1}$ ozone for 2 h. Leaf conductance and leaf water potential were determined on the first trifoliate.

ozone stimulated stress ethylene production) was compared with plants that were not ozone sensitive for the four different experiments (Fig. 5). Plants that had been in the water stress treatments for 4 to 10 days before measurement exhibited mean leaf conductances of 0.23 cm s^{-1} or less, while the plants that were not water stressed for the last 4 or 10 days had mean leaf conductances of 0.25 to 0.54. In each experiment, plants that showed no ozone response had significantly lower mean leaf conductances than the plants that responded to ozone. Heck et al. (1977) suggested that water stress during growth reduced plant sensitivity to ozone through physiologic changes within the plant, whereas similar stress conditions during exposure induced resistance through a reduction in stomatal aperture. Our data imply that the reduced ozone sensitivity associated with water stress during growth and/or exposure can be explained through changes in leaf conductance without invoking other factors.

REFERENCES

Adedipe, N.O., Khatamian, H. and Ormrod, D.P., 1973. Stomatal regulation of ozone phytotoxicity in tomato. Z. Pflanzenphysiol., 68: 323–328.

Anderson, V.L. and McLean, R.A., 1974. Design of Experiments: A Realistic Approach. Marcel Dekker, New York, 418 pp.

Dean, C.E. and Davis, D.R., 1967. Ozone and soil moisture in relation to the occurrence of weather fleck on Florida cigar-wrapper tobacco in 1966. Plant Dis. Rep., 51: 72–75.

Downs, R.J. and Hellmers, H., 1975. Environment and the Experimental Control of Plant Growth. Academic Press, New York, 145 pp.

Dunnett, C.W., 1955. A multiple comparison procedure for comparing several treatments with a control. J. Am. Stat. Assoc., 50: 1986–1121.

Harkov, R. and Brennan, E., 1980. The influence of soil fertility and water stress on the ozone response of hybrid poplar trees. Phytopathology, 80: 991–994.

Heck, W.W., Mudd, J.B. and Miller, P.R., 1977. Plants and microorganisms. In: Ozone and Other Potential Photochemical Oxidants. National Academy of Sciences, Washington, DC, pp. 437–585.

Hoffman, G.H., Maas, E.V. and Rawlins, S.V., 1973. Salinity-ozone interactive effects on yield and water relations of pinto bean. J. Environ. Qual., 2: 148–152.

Khatamiam, H., Adedipe, N.O. and Ormrod, D.P., 1973. Soil–plant–water aspects of ozone phytotoxicity in tomato plants. Plant Soil, 38: 531–541.

Lang, A.R.G., 1967. Osmotic coefficients and water potentials of sodium chloride solutions from 0 to 40° C. Aust. J. Chem., 20: 2017–2023.

MacDowall, F.D.H., 1965. Predisposition of tobacco to ozone damage. Can. J. Plant Sci., 45: 1–12.

McElroy, F.F., 1979. Transfer standards for calibration of air monitoring analyzers for ozone. U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Research Triangle Park, NC, EPA-600/4-79-056, 150 pp.

Markowski, A. and Grzesiak, S., 1974. Influence of sulfur dioxide and ozone on vegetation of bean and barley plants under different soil moisture conditions. Bull. Acad. Pol. Sci., 22: 875–887.

Moldau, H., 1973. Effects of various water regimes on stomatal and mesophyll conductances of bean leaves. Phytosynthetica, 7: 1–7.

Oertli, J.J., 1958. Effect of salinity on susceptibility of sunflower plants to smog. Soil Sci., 87: 249–251.

Olszyk, D.M. and Tibbitts, T.W., 1981. Stomatal response and leaf injury of *Pisum sativum* L. with SO_2 and O_3 exposures. II. Influence of moisture stress and time of exposure. Plant Physiol., 67: 545–549.

Paur, R.J. and McElroy, F.F., 1979. Technical assistance document for the calibration of ambient ozone monitors. U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Research Triangle Park, NC, EPA-600/4-79-057, 69 pp.

Rich, S. and Turner, N.C., 1972. Importance of moisture on stomatal behavior of plants subjected to ozone. J. Air Pollut. Control Assoc., 22: 718–721.

Sionit, N. and Kramer, P.J., 1976. Water potential and stomatal resistance of sunflower and soybean subjected to water stress during various growth stages. Plant Physiol., 58: 537–540.

Snedecor, G.W. and Cochran, W.G., 1967. Statistical Methods. 6th Edition. Iowa State University Press, Ames, IA, 593 pp.

Stan, H.-J., Schinker, S. and Kassner, J., 1981. Stress ethylene evolution of bean plants – a parameter indicating ozone pollution. Atmos. Environ., 15: 391–395.

Taylor, G.S., DeRoo, H.G. and Waggoner, P.E., 1960. Moisture and fleck of tobacco. Tob. Sci., 4: 62–68.

Tingey, D.T., 1980. Stress ethylene production – A measure of plant response to stress. HortScience, 15: 630–633.

Tingey, D.T. and Stockwell, C., 1977. Semipermeable membrane system for subjecting plants to water stress. Plant Physiol., 60: 58–60.

Tingey, D.T., Standley, C. and Field, R.W., 1976. Stress ethylene evolution: A measure of ozone effects on plants. Atmos. Environ., 10: 969–974.

Tingey, D.T., Pettit, N. and Bard, L., 1978. Effect of chlorine on stress ethylene production. Environ. Exp. Bot., 18: 61–66.

Walker, E.K. and Vickery, L.S., 1961. Influence of sprinkler irrigation on the incidence of weather fleck on flue-cured tobacco in Ontario. Can. J. Plant Sci., 41: 281–287.

Waring, R.H. and Cleary, B.D., 1967. Plant moisture stress: Evaluation by pressure bomb. Science, 155: 1248–1254.

Yang, S.F., 1980. Regulation of ethylene biosynthesis. HortScience, 15: 238–243.
Zur, B., 1966. Osmotic control of matric soil-water potential: I. Soil–water system. Soil Sci., 102: 394–398.
Zur, B., 1967. Osmotic control of matric soil-water potential: II. Soil–plant system. Soil Sci., 103: 30–38.